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TELEMETRY AND DATA PROCESSING SYSTEMS
FOR SCIENTIFIC SATELLITES

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First of all it is necessary that we define the scope of the space

effort in order that we can see just what area we are talking about.

First of all, the space exploration is divided into two major categories: military and civilian. I'm not going to say anything about the military space effort because, for one thing, it is highly classified and secondly, I know very little about it. On the other side we have the civilian space effort, which in the United States is again divided into two general categories of manned and unmanned. The general public is probably the most familiar with our manned space effort which successfully completed the Mercury Program in orbiting a number of astronauts around the earth and will be followed within this decade, according to plans, establishing some kind of manned exploration of the moon. This is the program, Appollo. The unmanned space efforts again can be broken down into several categories; these are, the exploration of the planetary system, the exploration of the moon, and the exploration of the earth in the earths relationship to the sun and the sun's planetary system. The mission of the GSFC in Greenbelt, Md., just outside Washington, D. C., is mainly concerned with this last area of research - that is, scientific satellites of the earth and occasionally of the moon in support of our general programs for gathering scientific knowledge about the universe. So when we talk about scientific satellites in this context today, we are talking about satellites mainly about the earth, but some of which may be in the region of the moon, and generally concerned with some type of scientific research. There are indeed a number of other unmanned satellites of the earth which are concerned with, first of all supporting

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our manned missions to the moon and some of Goddard's satellites fall into this category. As I'm sure you understand, there are certain radiation problems or hazards concerned with interplanetary travel. Before these can be successfully circumvented, these hazards must be investigated and means for nullifying their effects determined. A good bit of our scientific investigation has this practical aim. Another category of satellites of the earth which we will not be discussing this morning are so-called "application" satellites. These are the familiar Tiros and Nimbus satellites which are concerned with meteorology (or weather) and the Relay, Echo, and Syncom satellites which are concerned with communications.

So now we can concentrate on some scientific satellites. These again we divide into different categories depending on their missions, and we can also make a subdivision on the basis of complexity and size; for example: as to mission, there are satellites which are designed to study the atmosphere of the earth and its structure. There are satellites carrying experiments which are designed to measure the magnetic field of the earth and energetic particles such as cosmic rays, electrons, protons, etc. And there is another whole class of satellites, the main purpose of which is to study earth-sun relationships and to gather knowledge concerning the sun, its spectra, its composition. As you read about these various satellites in the newspapers, you generally find that the type of satellite that we're concerned with this morning usually carries some popular name such as Explorer XII or some such designation. The earliest of these satellites, starting off with the Vanguard satellite, which was the precursor of the Goddard series, were very small satellites which were generally

designed for some special purpose. The initial Vanguard satellite, for example, had a very primitive telemetry system and its main utility was in measuring the characteristics of space as evidenced by the drag in its orbit of the atmosphere and in the perturbations of the orbit due to the irregularity of the shape of the earth. As a successor to this satellite had been a number of satellites with so-called geodetic satellites designed to study the surface and shape of the earth. As we became more used to designing satellites and launching them into space, their experiments became more numerous and more complicated and gradually have come to be divided into these various classes of satellites, which in their most recent ones, have tended to be called "observatories" because of the variety of functions that they performed and the very latest generation of satellites, the first of which was launched a few months ago, was the so-called orbiting Geophysical Observatory, nick-named OGO. Another series of this general nature of large complicated satellites is the Orbiting Solar Observatory and again the Orbiting Astronomical Observatory. The concept of the observatory satellites is that there will be scheduled a number of large satellites being launched at more-or-less regular intervals. Each satellite will be able to accommodate a relatively large number of experiments; perhaps as large as twenty or even forty, and that as numerous universities and researchers throughout the United States and the world get experiments ready, they will be scheduled to fly on one of these regular observatory flights of the particular category that the experiment fits into. In addition, there remains a number of satellites which continue to be launched to carry out specific missions, and at the present time, it is difficult to say how the proportion of space research will be carried out in the future; whether it will be by large observatories or a larger number of small satellites designed for specific missions.

The reasons for giving you this rather lengthy preamble is to set the stage to show you why there are a great variety of telemetry systems used in scientific satellites. Due to the variety of size, missions, complexity of satellites, there are a number of telemetry systems used on them.

The first satellites used versions of the standard rocket range telemetry systems of which FM/FM PAM and PDM are typical. As a separate development of the Vanguard satellite, was a type of telemetry which has come to be known as Pulse Frequency Modulation, or PFM. All of these systems had tended to go through a period of development as the satellite technology has developed, with the result of there being a great variety of satellite telemeters, none of which, at the present moment, are completely standardized. The second outstanding characteristic of satellite telemetry is the quantities of data involved which must be carried by the telemetry system. For example, on the Aerial satellite during a year's expected life in orbit, we expected a maximum of 15×10^8 data points to be transmitted; now Aerial was a relatively complex satellite having roughly a half dozen experiments aboard and it transmitted fifty samples of data per second during the time that it was transmitting. Let us contrast Aerial with OGO, which has the capability of transmitting 7000 data points per second continuously for a full year. Now if Aerial could transmit approximately 10 data points for every person in the United States during its life time, you can imagine the quantity of data which would be transmitted by the Orbiting Geophysical Observatory. Now, because of the very large quantity of data expected from these satellites, it was very early decided that the only feasible means for handling this data expeditiously and putting it in a form which would be useful to the experimenter would be by semi-automatic or automatic means. The

most capable device for handling large quantities of data automatically at the present time is digital computer. So the first step in the job is to take telemetry signals and translate them into some form in which they can be entered in the digital computer. These translating devices are termed digitizing lines or sometimes signal processing lines and an acronym has been coined from them at Goddard - we refer to them as the STARS Lines "S.T.A.R.S." standing for Satellite Telemetry Automatic Reduction System. These STARS Lines take the telemetry signals which have been recorded at stations throughout the world at telemetry receiving stations and there recorded on magnetic tape which is sent back to the United States. These magnetic tapes are played on analog tape reproducing machines into the STARS Lines for signal processing. This signal processing consists of several steps: First, there is the so-called signal conditioner. The occasion for the signal conditioner is due to the fact that most scientific satellite telemetry is received at a very low signal-to-noise ratio. This in turn is due to the fact that scientific satellites being small are severely limited in the amount of power that they can expend in sending back the information, in addition to which the distances covered may run up into the hundreds of thousands of miles. The signal conditioner then is some kind of device which is used for filtering noise and enhancing the signal-to-noise ratio so that the signal can be properly digitized. The second major function performed by the STARS Line is synchronizing. Synchronizing consists of recovering the sampling rate and establishing a frame of reference in the data so that data which has been time multiplexed can be then separated into its original constituent part. Once the telemetry signal has been conditioned and synchronized it is digitized and put in a buffer. The buffer is simply a magnetic core memory;

the function of which is to provide a temporary storage to make up for the fact that data flows into it at one rate and must be read out of it onto a digital magnetic tape at some higher rate. The STARS Line then receives telemetry signals on analog tapes and digitizes them and places them on digital magnetic tapes suitable for computer entry. The one other dimension necessary to this process is to decode a time signal which has generally been placed on the tape in the telemetry station and properly decoded and formatted and interlead it with the data on the digital magnetic tape. The purpose of this is that in any experiment of space the experimenter wishes to be able to accurately define his data in terms of its location. Now since the data is not received with a location tag, the time of its reception is recorded along with it. Some time after the fact then of receiving the data, we can determine from the satellite its position in space as a function of time and then using its orbital data we can correlate our experimental data with the orbital position against the common denominator of time. Now all of this may sound very straightforward, but one thing which I wish to impress upon you is the fact that this system of processing data as described so far evolved rather slowly and is still in a process of evolution. Space technology is a new art; mounting experiments in space is a new science; it is changing rapidly every day, and there are a whole host of technological problems involved in the processing of this data which run hand-in-hand with the basic scientific problems which we are trying to establish about the earth in which we live and the universe that it inhabits, so that as I describe an automatic telemetry reduction system and were I to show you pictures of it, you might get the idea that here we have established facts and that perhaps one might think that most of the problems involved in

processing telemetry data have already been solved and this is indeed very far from the case. If there is one idea that I would like to convey to you here today, it is that this is a challenging area in electronic technology. It may not be as glamorous or attract as much notice from the public as an astronaut does in orbiting the earth or flying to the moon, however, there is a great deal of useful scientific work to be done in this field.

Following the automatic digitizing process in the STARS Lines, we take the digital magnetic/tapes and put them on automatic digital computers for a purpose of further processing the data. The first step, of course, is in what might be termed a quality control function. Digital computers are machines which require a very high uniformity of input signal, and starting with telemetry signals which may be weak, fluctuating, and variable, we have to, in some manner, produce a uniform product for the computer to work on to keep it from being confused, so our first step in the digital computer is culling data, smoothing data, smoothing time, and rearranging the data in the suitable form for its further processing with the digital computer. Once this has been achieved to an adequate degree, it is necessary that the data which belongs to each individual experimenter must be segregated and placed on a separate digital magnetic tape so that it can be given to the correct recipient. This is necessary for a variety of reasons. First of all, most experimenters would not want to have their data mixed in with the data of every other experimenter in such a way that it would be difficult for him to retrieve his own data, and secondly, some experimenters do not wish other experimenters

to see their data, so that rather than give each experimenter a copy of the master data tape and leave it to him to strip out his data, this is done in what is called a decommutating operation. In the case of the OGO satellite, for example, we come off of the STARS Line with the digital tape, put it on a large digital computer, go through quality control and decom, and come out with as many as twenty digital tapes, each containing the data for one experimenter. These tapes are then sent or mailed to the experimenter for further data processing and analysis. The ultimate aim of an experimenter, of course, is to determine something from his data that can be published in a scientific journal, so that the immediate end to his experiment is to take his large series of numbers which constitutes his data, reduce it to some order which can find as a basis of some inductions of his represent the results of his experiments in a publication, a chart, or a graph or description of some physical set of facts, and the reduction of this data from his data tape involves a surprisingly large and varied number of operations again generally done on a large scale digital computer.

Now, let us for a moment look back then over the whole field of satellite telemetry data processing in trying to outline what some of the problem areas are. First of all, there are organizational problems; that is, we are just gaining experience in the setting up of organizations which can handle expeditiously large quantities of data of a very heterogeneous nature, so we have problems in organization and management of running a new scientific endeavor, and truly the data processing is a new scientific and engineering endeavor. Next we have a series of related problems of determining the most advantageous type of telemetry system to use for a specific type of data or a specific type of satellite, and this problem is presently engaging the attention of a large number of scientists and engineers.

Thirdly, in the reduction of this data once it reaches the central data processing area, there exists a number of plans of attack on how to reduce the data. You've heard me describe the STARS Lines, which is an automatic digitizing, signal conditioning, buffering machine. But there are questions as to whether this is the optimum way in which this data could be processed. The next logical step on this problem is to have these automatic lines operate under control of a digital computer in such a way that the process can be varied either by the will of the operator by beforehand, or a priori knowledge or as the result of an adaptive process in the processor itself, and as part of this general problem of the kind of equipment to use, we have the discussion being mooted as to whether we should use a general purpose machine or a special purpose machine. There are technical arguments as to the satisfactoriness of each approach, as to the cost of each approach, and as to the expediency of each approach. We find that the determination of the type of data reduction system we are going to use involves a knowledge of first of all, the experiment, the satellite, the telemeter, the data reduction machine, and the intent on the part of the experimenter as to what he wants to accomplish.